

LARGE CONCRETE PILES

Pile economy is measured in units of load carrying capacity—not in number of piles or linear feet. A large pile, costing \$70 in place, that will carry 70 tons is more economical than two piles costing \$40 each that will carry a total of 50 tons.

The only limitation on the size of concrete piles is the equipment necessary to handle and drive them.

For hundreds of years the natural growth of trees governed the size and length of piles. Man had to take what he found and, through long experience enriched somewhat by slowly developed theory, a practice and technique in the use of piles grew around the limitations imposed by nature's supply of ready-made material. Thus, the technique of construction crystallized on handling and driving wood piles and the load carrying capacity, both by formula and experience, was based on a relatively small and non-uniform size.

The development and manufacture of concrete piles has removed nature's limitation on the size and hence the carrying power of piles.

Capacities, Large vs. Small Piles

A pile carries its load by direct pressure on the "point" and by "skin friction." In most instances, the latter is the more important. In most soils the skin friction on piles not in a cluster is increased by compression of the surrounding earth in driving—the larger the pile, the greater, in extent at least, the compression. A cluster of piles may yield by subsidence of the "bulb of pressure" in which case the entire cluster settles, and the average load carried per pile may be less than the load a single pile in the same soil would carry.

In a trestle bent, the fewer piles used, the farther apart they will be, and consequently the condition for their action as individual piles is better satisfied. The load on each pile of a 3-pile trestle bent can, with propriety, be taken as equivalent to the capacity of an individual pile in the same soil.

Since the bearing power of an individual pile is equal to point bearing plus skin friction, we have, as a comparison of pile capacities—

Pile section area $\times$ direct bearing on soil at "point" + surface area in ground $\times$ coefficient of friction. This is represented very simply by,
 $Ap + Sc \dots \dots \dots (1)$

in which

A = Cross-sectional area of pile in direct bearing.

p = Direct bearing power of soil.

S = Surface area of portion of pile in ground.

c = Coefficient of friction between earth and pile.

Regardless of theoretical bearing power formulas (some complicated), (1) is a simple statement of how a pile carries its load. For a reliable estimate of total capacity it is only necessary to determine p and c for the soils at the site and for the size of piles.

Compare on this basis the load capacity of two piles, one 11-in. diameter round, and a larger one, 24-in. diameter and octagonal in section:

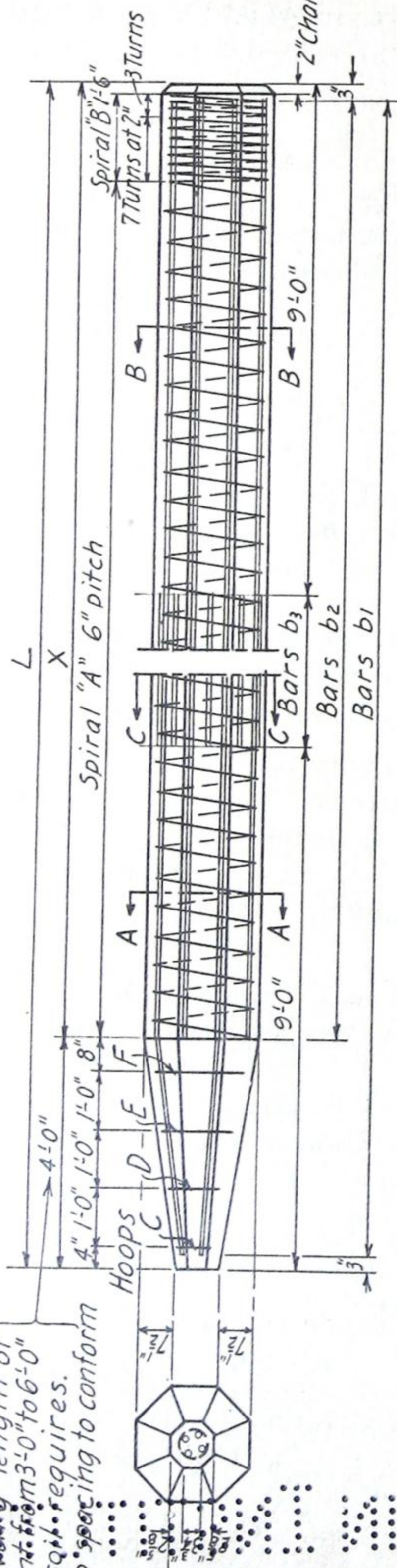
Sectional area, 24-in. octagonal	= 3.31 sq. ft.
Sectional area, 11-in. round	= .66 sq. ft.
Surface area 24-in. octagonal—	
20-ft. penetration	= 132 sq. ft.
Surface area 11-in. round—	
20-ft. penetration	= 57 sq. ft.

Thus, the large pile has 5 times the point bearing and $2\frac{1}{3}$ times the surface area in contact with the soil.

Interpreting this by assigning values to direct bearing on soil and coefficient of skin friction, we have, for bearing on soil = 10 tons; and coefficient of friction = 1000 lb./sq. ft.

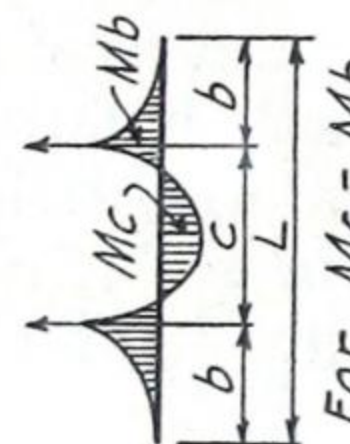
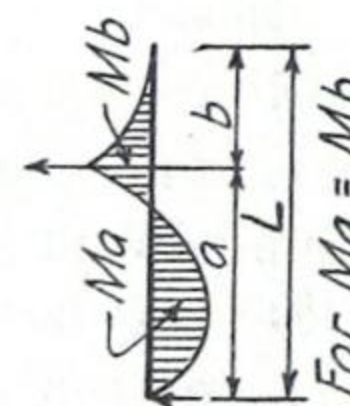
Bearing, 24-in. octagon pile	= 3.31×10	= 33.1
Friction, 24-in. octagon pile	= $132 \times \frac{1000}{2000}$	= 66.0
Total for 24-in. pile		99.1 tons
Bearing, 11-in. tapered round pile	= $.66 \times 10$	= 6.6
Friction 11-in. tapered round pile	= $57 \times \frac{1000}{2000}$	= 28.5
Total for 11-in. pile		35.1 tons

Verify length of point from 3'-0" to 6'-0" as sq. ft. requires. Hoop spacing to conform



SECTION A-A & B-B
FOR ALL PILES
HAVING "b3" BARS

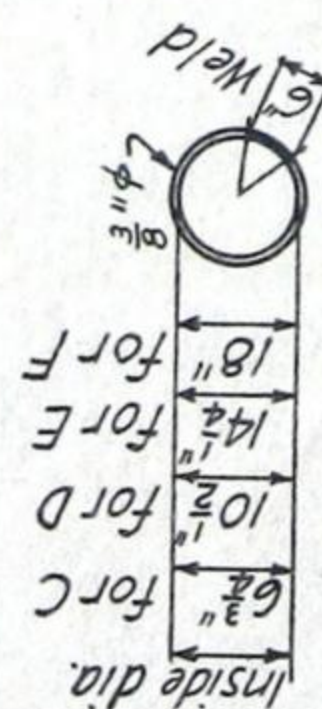
SECTION C-C
FOR ALL PILES
HAVING "b3" BARS



ONE POINT PICKUP
For $M_a = M_b$
 $a = 0.707L$ $b = 0.293L$

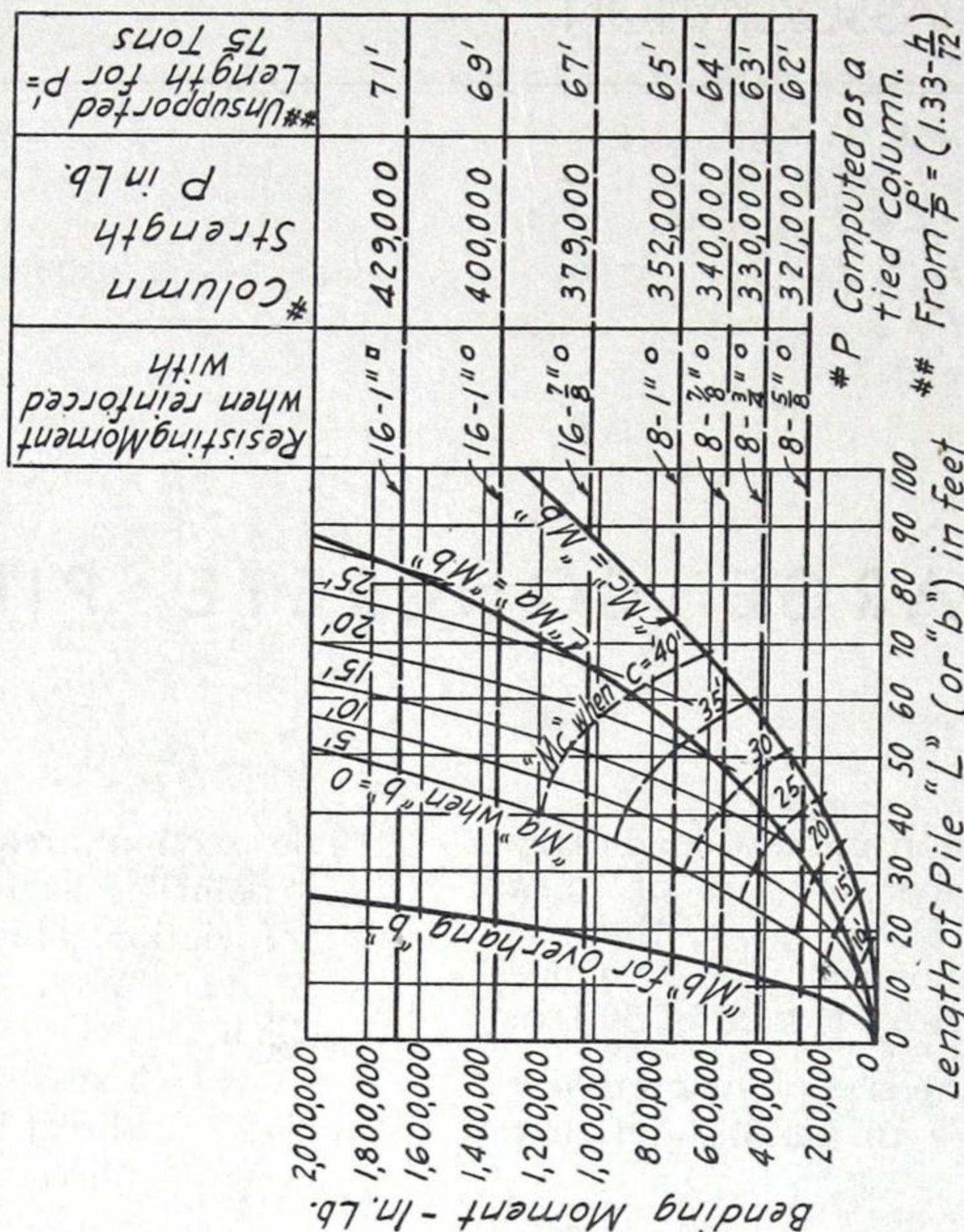
TWO POINT PICKUP
For $M_c = M_b$
 $b = 0.207L$ $c = 0.586L$

HANDLING STRESSES
For One Point Pickup.
"Ma" governs the design above the line $M_a = M_b$
For a Yoke or Two Point Pickup.
"Mc" governs above the line $M_c = M_b$.



HOOPS C-D-E-F

1-Bar- $\frac{3}{8}$ " x 1'-10" - C
1-Bar- $\frac{3}{8}$ " x 2'-10" - D
1-Bar- $\frac{3}{8}$ " x 3'-10" - E
1-Bar- $\frac{3}{8}$ " x 4'-10" - F



* P Computed as a tied column.
** From $P = (1.33 - \frac{L}{72})$

REINFORCEMENT REQUIRED FOR HANDLING

Cross Section
Perimeter 477 sq. in.
Core diameter 79 in.
Core area 21 in.
Concrete in 4 ft. point 346 sq. in.
Concrete in "X" per ft. 0.123 c. y.
Weight of point (4 ft.) 1000 Lb.
Weight of "X" per ft. 498 Lb.

GENERAL NOTES
Specifications from A.R.E.A. Manual.
Class of concrete 3500
Permissible pile load $P = 75$ tons

BILL OF BARS (FOR PILES WITH 4 FT POINT)

Length L	Straight X	LONGITUDINALS						SPIRALS						HOOPS				Vol. of Pile C.Y.	Wt. of Pile Lb.	
		b1 (bent)		b2		b3		Wt. in Lb.	A			B			C	D	E			F
		Size	No.	Length	No.	Length	No.		Length	No.	Wt. Lb.	No.	Wt. Lb.							
20'	16'	3/8" 4	19'-6"	4	15'-9"		147	One	29	48	One	10	One (Wt. 9 Lb.)	One (Wt. 13 Lb.)	One (Wt. 16 Lb.)	One (Wt. 20 Lb.)	2.22	9000		
25'	21'	5/8" 4	24'-6"	4	20'-9"		189		39	64							2.83	11900		
30'	26'	3/4" 4	29'-6"	4	25'-9"		232		49	80							3.45	14000		
35'	31'	7/8" 4	34'-6"	4	30'-9"		532		59	96							4.06	16500		
40'	36'	1" 4	39'-6"	4	35'-9"	8	975		69	112							4.68	18900		
45'	41'	1 1/8" 4	44'-6"	4	40'-9"	8	1140		79	128							5.29	21400		
50'	46'	1 1/4" 4	49'-6"	4	45'-9"	8	1700		89	144							5.91	24000		
55'	51'	1 1/2" 4	54'-6"	4	50'-9"	8	1910		49	160							6.52	26400		
60'	56'	1 5/8" 4	59'-6"	4	55'-9"	8	2125		54	178							7.14	28900		

24" REINFORCED CONCRETE
OCTAGONAL PILE

blocks in transit, uneven level of blocks or distribution of load, and vibration and jarring in transit.

Shipping and handling stresses may exceed the working stresses used in design without material injury to the piles, so long as they are well within the elastic limit of the steel. Distributed and relatively small tension cracks in piles are not serious because, under load, piles are in compression and simple tension cracks are tightly closed.

The blocking under piles loaded on cars or stacked on the ground in tiers should be approximately in a vertical plane. Haphazard arrangement of the blocking may bring a large part of the entire weight of all piles above a certain tier on the piles or a pile of the lower tier.

The cost of very long piles may be materially reduced by providing for pick-up at several points so as to reduce handling moments to a minimum. Reinforcement is the largest single item of cost of concrete piles, and where a considerable number of long ones are used, the saving in reinforcement made possible by special handling devices may be much greater than the cost of these devices.

Cost

Quantities of concrete and steel are shown on page 2 for various lengths of 24-in. octagon piles. Appropriate unit prices applied to these quantities will give the cost per foot.

Manufacturing costs in a casting yard of a mid-western railway for the period December 1, 1933, to November 30, 1934, inclusive, were as follows:

Average Cost Per Foot of 24-in. Octagon Piles Ranging From 25 ft. to 60 ft. Long

Cement.....	\$0.29519
Ready Mixed Concrete.....	.30736†
Reinforcement.....	.43089
Labor.....	.17024
Miscellaneous*.....	.08233
Total.....	\$1.28601

The average cost per foot for various pile lengths was as follows:

Length	Cost per Foot
25 ft.....	\$1.0382
30 ft.....	1.1051
31 ft.....	1.1488
35 ft.....	1.1849
40 ft.....	1.3516
45 ft.....	1.3775
50 ft.....	1.5234
55 ft.....	1.5467
60 ft.....	1.5866

Practically all of the difference in cost of the piles is in the reinforcement which, of course, must be greater in the longer piles to provide for handling stresses.

The average cost of driving 24-in. piles, as determined by a midwestern railway system, is about 60 cents per ft., including digging holes, setting guide template and handling at the site.

Cost Per Ton Capacity

The cost per ton of capacity is the only correct basis for comparing the cost of different sized piles. On page 3 it is shown that for the soil resistance assumed a 24-in. octagon concrete pile has 2.8 times the load capacity of a round pile averaging 11 in. in diameter. The large pile must then cost in place 2.8 times as much as the smaller pile for parity in first cost.

From the above cost data we have for a 35-ft. 24-in. pile:

Manufacture.....	\$1.185 per ft.
Driving.....	.65 per ft.
Handling, Transportation, and Miscellaneous.....	.20 per ft.
	\$2.035 per ft.

Parity in first cost would then require that the smaller pile cost not to exceed 73 cents per foot in place.

Comparison of a 35-ft., 11-in. (av. diam.) pile on a ton capacity basis is more direct as follows:

Manufacture.....	\$0.50 per ft.
Driving.....	.35 per ft.
Handling, transportation and miscellaneous.....	.10 per ft.
	\$0.95 per ft.

Assuming 25 tons for this pile, the cost per ton load capacity = \$1.33.

The capacity of the 24-in. at 2.8 times the smaller would be 70 tons, and the cost per ton = \$1.02.

This result is substantiated by the fact that concrete piles were substituted for creosoted wooden piles to carry the new import-export pier of the Pennsylvania Railroad in Baltimore at no extra cost to the railroad company.

Specifications

Proposed revised specifications for manufacturing, handling and driving premolded reinforced concrete piles are published in A.R.E.A. Bulletin No. 374, pages 841 to 842. They are as follows:

PROPOSED REVISED SPECIFICATIONS FOR CONSTRUCTING PREMOLDED CONCRETE PILES

1. The workmanship, materials and proportioning shall conform to the Specifications for Concrete Plain and Reinforced of the American Railway Engineering Association, with the following modifications:

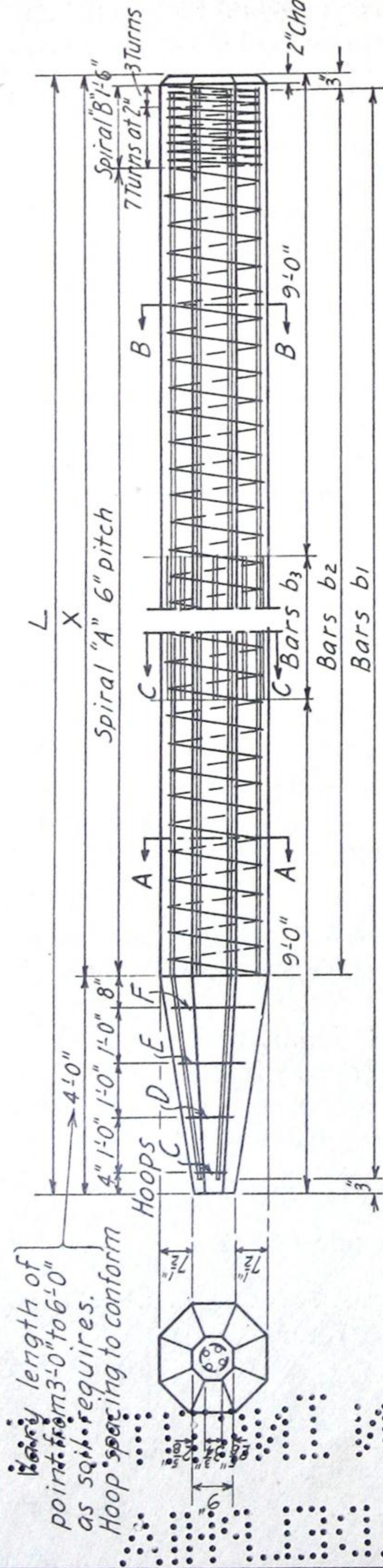
(a) *Aggregates*—The maximum size of the

coarse aggregate shall be not more than 1 in. nor more than $\frac{3}{4}$ of the minimum clear spacing of reinforcement or the minimum distance from reinforcement to forms.

2. Class of Concrete

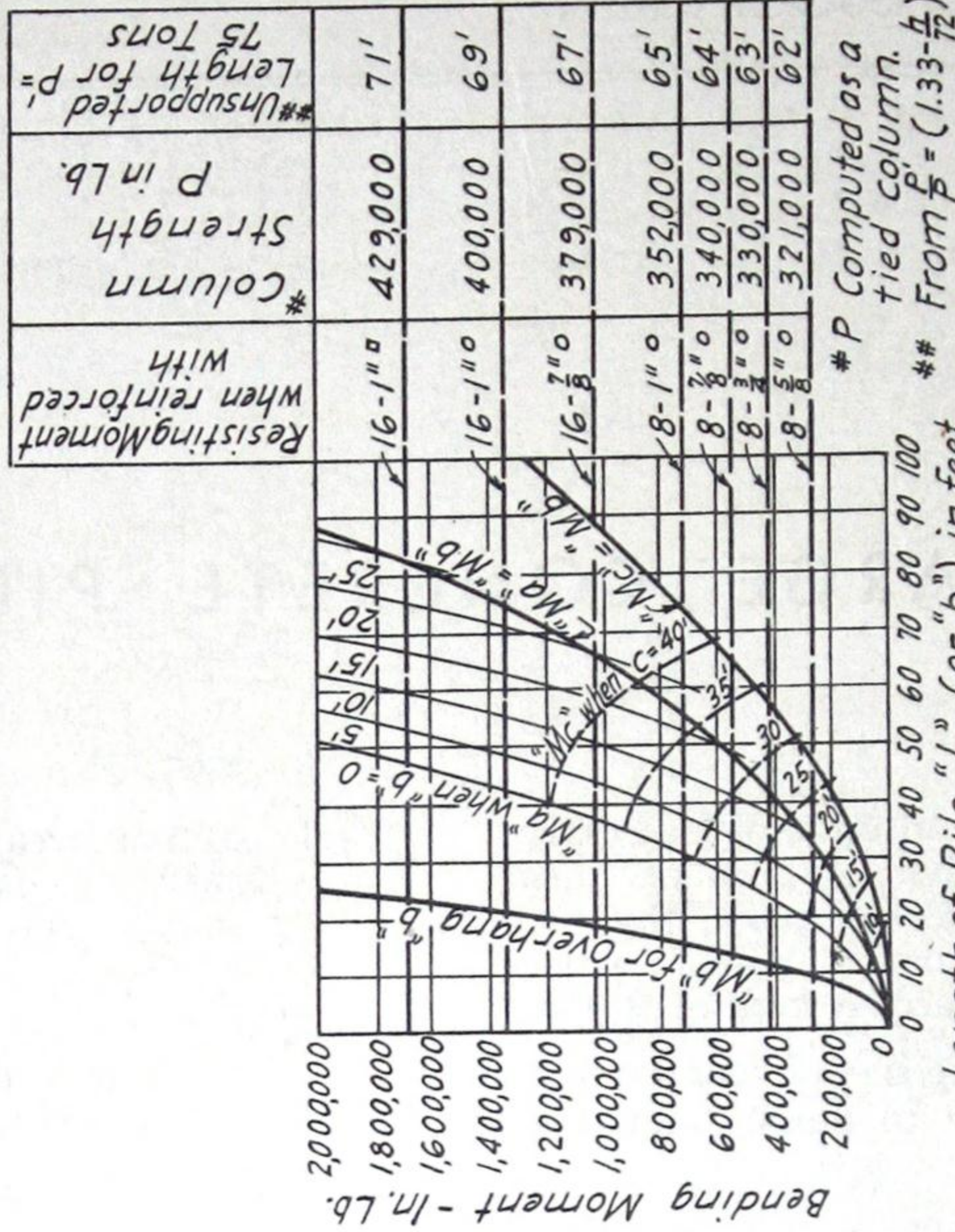
The concrete shall be class 3500, using not more than 5 gallons of water per sack of cement.

*The item "Miscellaneous" amounts to about 6.8% of the total of the other items.
†Cement purchased by railroad.



SECTION CC
FOR ALL PILES
HAVING "b₃" BARS

SECTION A-A & B-B
FOR ALL PILES

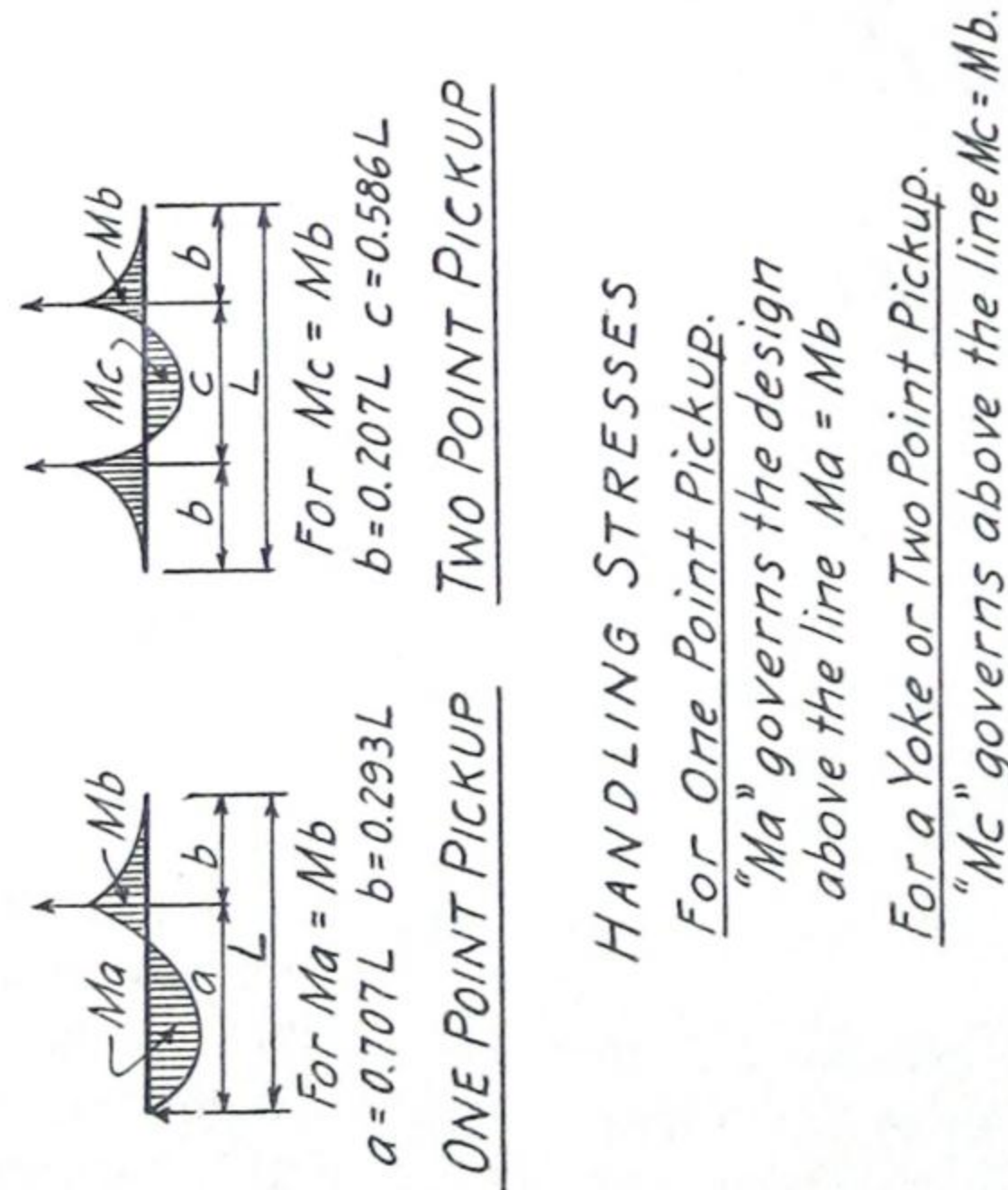


REINFORCEMENT REQUIRED FOR HANDLING

GENERAL NOTES
Specifications from A.R.E.A.
Manual.
Class of concrete 3500
Permissible pile load $P = 75$ tons

Cross Section
Perimeter 477 sq. in.
Core diameter 21 in.
Core area 346 sq. in.
Concrete in 4 ft. point 0.248 c. y.
Concrete in "X" per ft. 0.123 c. y.
Weight of point (4 ft.) 1000 lb.
Weight of "X" per ft. 498 lb.

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OCTAGONAL PILE



HANDLING STRESSES
For One Point Pickup.
"Ma" governs the design above the line $M_a = M_b$
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HOOPS C-D-E-F

1-Bar- $\frac{3}{8}$ " x 1'-10" - C
1-Bar- $\frac{3}{8}$ " x 2'-10" - D
1-Bar- $\frac{3}{8}$ " x 3'-10" - E
1-Bar- $\frac{3}{8}$ " x 4'-10" - F

BILL OF BARS (FOR PILES WITH 4 FT POINT)

Length L	Straight X	LONGITUDINALS				SPIRALS				HOOPS				Vol. of Pile C.Y.	Wt. of Pile Lb.
		b ₁ (bent)	b ₂	b ₃	Wt. in Lb.	A	B	C	D	E	F	G	H		
20'	16'	4	4	4	147	29	48	10	10	10	10	10	10	2.22	9000
25'	21'	4	4	4	189	39	64	10	10	10	10	10	10	2.83	11900
30'	26'	4	4	4	232	49	80	10	10	10	10	10	10	3.45	14000
35'	31'	4	4	4	275	59	96	10	10	10	10	10	10	4.06	16500
40'	36'	4	4	4	318	69	112	10	10	10	10	10	10	4.68	18900
45'	41'	4	4	4	361	79	128	10	10	10	10	10	10	5.29	21400
50'	46'	4	4	4	404	89	144	10	10	10	10	10	10	5.91	24000
55'	51'	4	4	4	447	99	160	10	10	10	10	10	10	6.52	26400
60'	56'	4	4	4	490	109	176	10	10	10	10	10	10	7.14	28900

Thus, the 24-in. pile has 2.8 times the load capacity of the 11-in. round pile. Loading tests show this comparison to be conservative, for four reasons. This example makes no allowance for (1) higher coefficient of friction from greater ground compaction around the larger pile, nor for (2) greater adhesion between the earth and the rough concrete surface. (3) It also assumes that the soil bearing power p is the same whether the bearing area is partly in the taper, or at the point as is the case with the concrete pile. A tapered pile of 11-in. average diameter may have a 14-in. butt and only an 8-in. point. Assuming that the pile has been successful in reaching a hard stratum, the *average* unit vertical bearing power of the taper may be only about one-fourth of that at the point, and the total "point" bearing capacity of the pile 4.3 instead of 6.6 tons. (4) The skin friction coefficient probably increases with the depth penetrated, in which case the area of the tapered pile is least where the friction is greatest.

Design

Shown on page 2 is the design for 24-in. concrete piles of the American Railway Engineering Association (Bulletin No. 374, page 855).

Except for very heavily loaded piles deriving their principal support from "point" bearing on a hard stratum, the column strength of piles is not even approached. Page 2 shows column load capacities of 24-in. octagon piles computed for class 3500 concrete (A.R.E.A. Manual 1929) of from 160 tons to 215 tons for an unsupported length of 12 times the diameter. Applying the load reduction formula (A.R.E.A.) for unsupported length, we have 75 tons capacity for unsupported lengths of from 62 ft. to 71 ft. These data show that in the design of ordinary concrete piles it is only necessary to provide sufficient reinforcement for handling and shipping and that the pile so designed will have several times the load capacity as a column that it will be called upon to carry as a pile. In other words, piles are designed as *piles*—not as columns.

Choice of Cross-Section

The shape of the pile section is influenced by considerations of appearance, manufacture, handling, driving and cost. Appearance is often of little importance and individual preference will govern the choice of square, hexagonal, octagonal or circular.

Advantages of the square section: placement of concrete and positioning of reinforcement simplified; effective depth for handling moments greater; surface area greater for given cross-sectional area than for other sections; forms simple and removal of piles facilitated.

Disadvantages: assembly of reinforcement into square cages is somewhat higher in labor cost, since fabricated spirals or completely assembled cages can be purchased for a circular assembly of

reinforcement. In some soils, especially where boulders and other obstructions are encountered, the square section may tend to rotate in driving more than other sections.

Other factors influencing choice of shape are obscure. Certainly, computation of effective depth for resistance to bending of hexagon, octagon and circular sections is complicated as compared with the square section. The square section will nest better in stacking and shipping than any other section.

Page 2 shows a minimum covering of reinforcement of $1\frac{3}{4}$ -in. less the thickness of the hooping. A minimum covering of 1-in. is provided in the A.R.E.A. general specifications for concrete and 3-in. for reinforced concrete in sea water. These coverings are ample but should not be violated by careless placement of reinforcement.

Manufacture

The casting plant should be located at a point where materials and labor are cheap. Sufficient space should be available to establish an efficient routine or "flow line" of operations.

Starting at one end, it is usually recommended that the flow line include: reinforcement cage assembly with bar storage racks, bending tables, templates for holding longitudinal bars, and assembly "horses." Next comes the casting section proper, including forms in gangs of sufficient number to permit continuous casting. The casting crew cleans and lines forms, positions reinforcement cages and works the concrete into place.

For intermittent operation it may be most economical to purchase concrete from a commercial ready-mix plant, thus avoiding overhead charges on idle equipment. Vibratory placement of concrete will permit the use of a lower water-cement ratio, and therefore shorten the initial curing period required to attain 2500-lb. strength. For continuous operation, this saving in time reduces the number of forms required and therefore the cost of manufacture.

Handling and Driving Equipment

While equipment intended for light wood piles has been successfully used for handling and driving concrete piles, the full advantage of the larger concrete piles cannot be realized unless equipment sufficiently powerful is provided. 24-in. reinforced concrete octagon piles weigh about 500 lb. per lin. ft. A 35-ft. pile will weigh close to 9 tons and a 50-ft. pile, 13 tons. With suitable equipment, however, the large piles can be handled and driven as quickly as smaller ones.

The original purpose of leads on a pile driver was to furnish guides for the hammer in the days of drop hammers. The steam hammer removes the need for leads, and wherever other means of guiding the piles are readily available leads should be dispensed with. A pile driver with fixed leads is not

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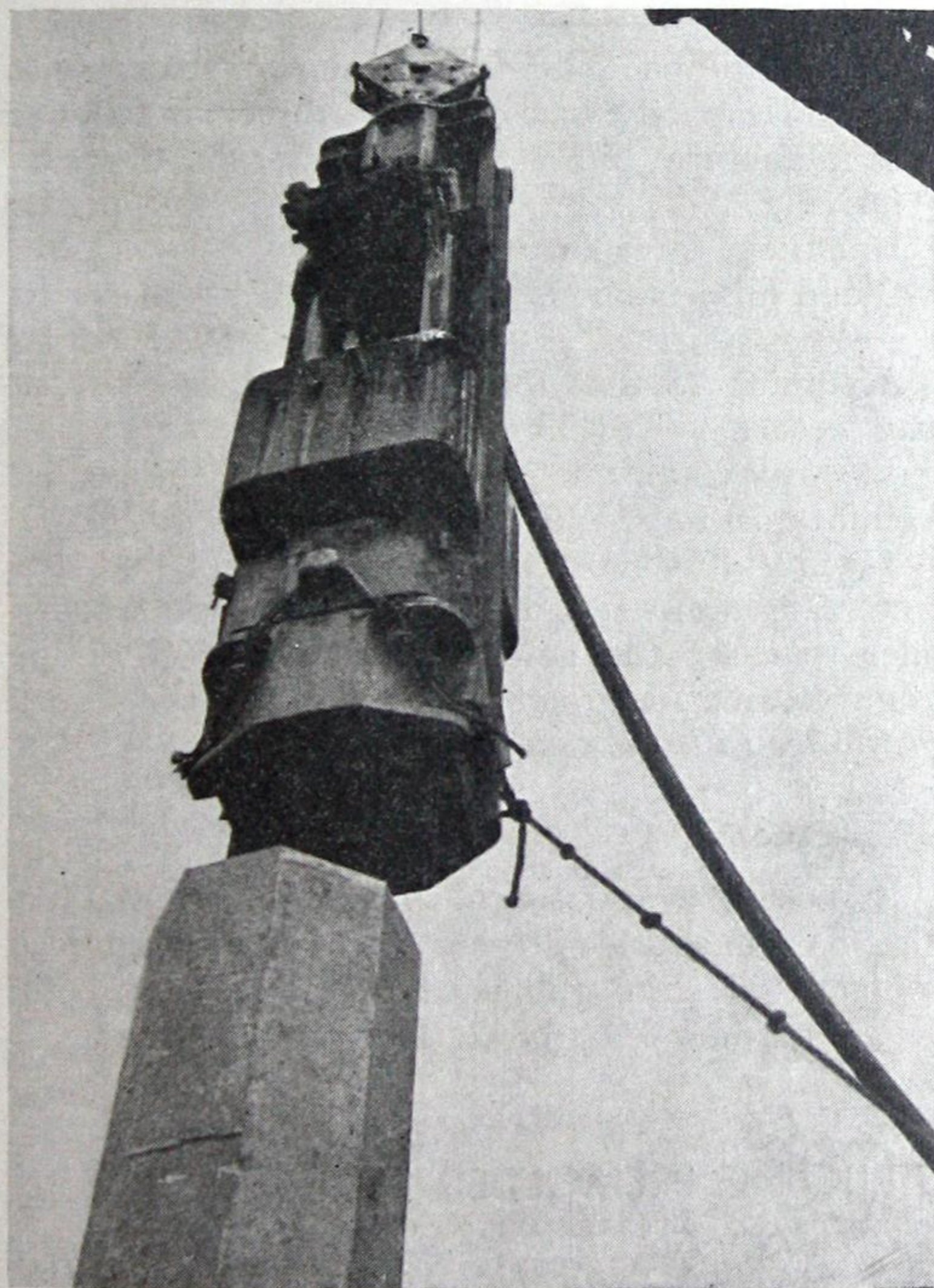
a good crane, and presents obstacles to shipment and movement at the site of work.

Large piles require correspondingly powerful equipment. A Vulcan No. 0 or heavier hammer should be used for 24-in. diameter concrete piles. A hammer heavier than a No. 0 has been provided by weighting the ram of a standard No. 0 to obtain a 9000-lb. ram.

A driving cushion consisting of an oak or gum block, 4 to 6 in. thick and conforming to the pile section, is used. Two to four piles are driven with one block.

The hammer is provided with a bonnet that fits over the head of the pile and contains the cushion block.

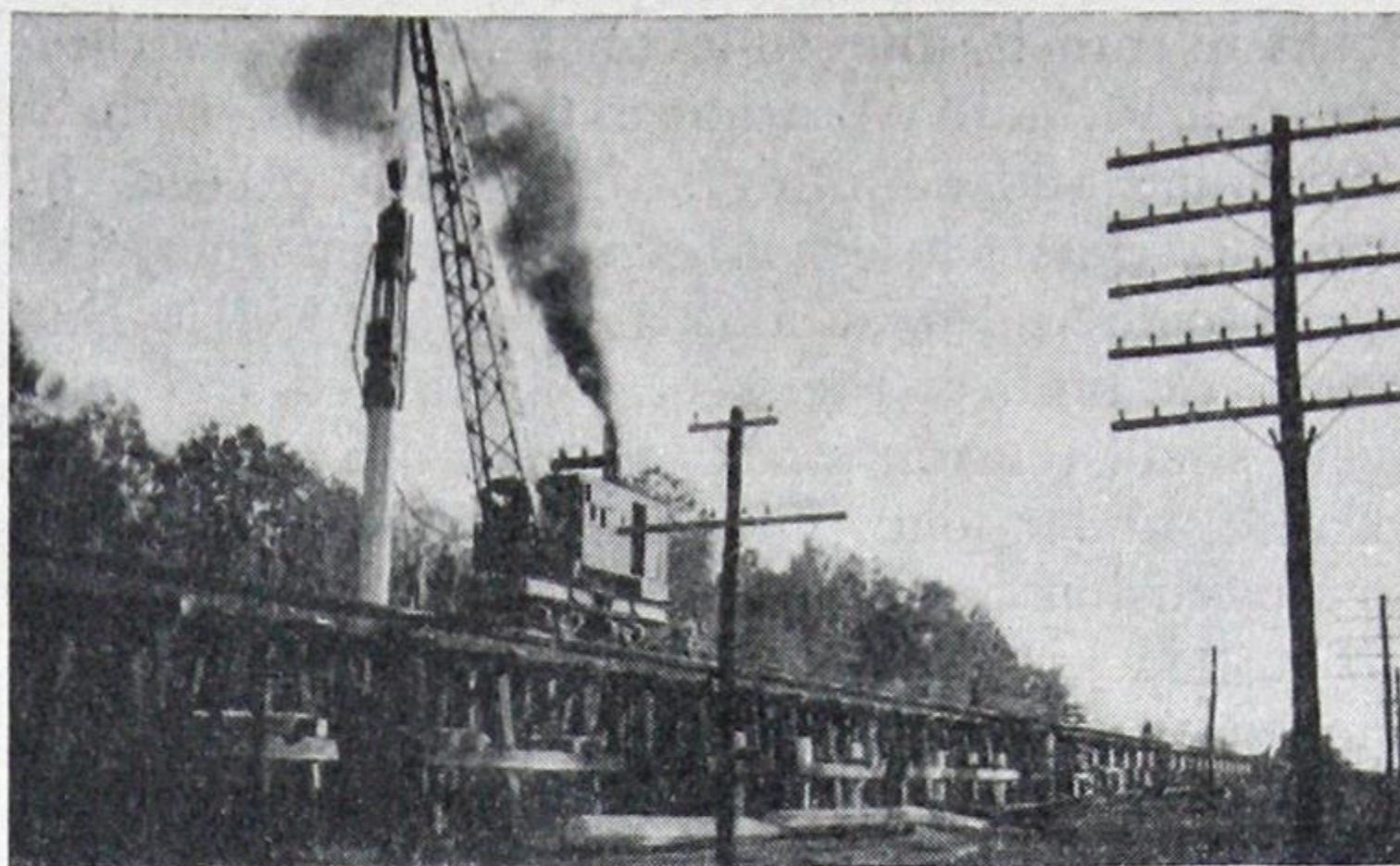
The crane should have a capacity of about 40 tons on a 12-ft. boom radius to handle the larger piles and the big hammer efficiently, although smaller cranes have been used. It should be equipped with an oversize boiler (about 66-in.) and have a two-speed travel on the track—the higher speed being 15 to 20 m.p.h. Such a crane clears for traffic under its own power and can be used for switching a mixer car used for casting caps and collars and for such other switching at the site as is required. Eighteen 55-ft. 24-in. trestle piles have been driven in an eight-hour day.



Ready to set heavy hammer on pile

Splicing and Cut-Off

The length of piles designed for a particular penetration is often found to be too long or too short. If the pile "brings up hard" before the



Driving 24-in concrete piles without leads

assumed penetration is reached, it must be cut off. If it is "going easy" when penetration is reached, it is good practice to continue driving until desired resistance is reached—in which case the pile must be spliced. Both splicing and cutting off are simple operations with concrete piles.

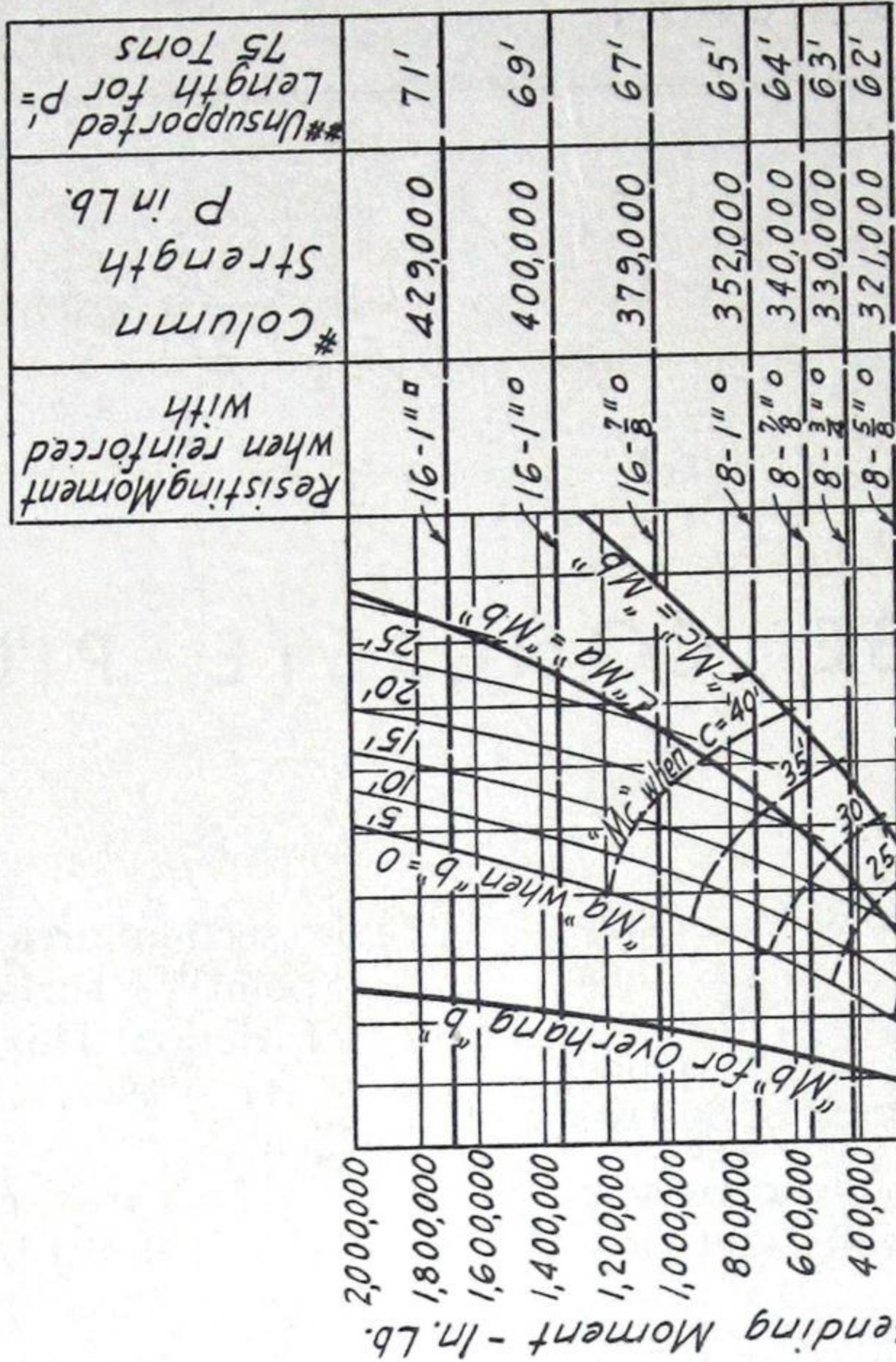
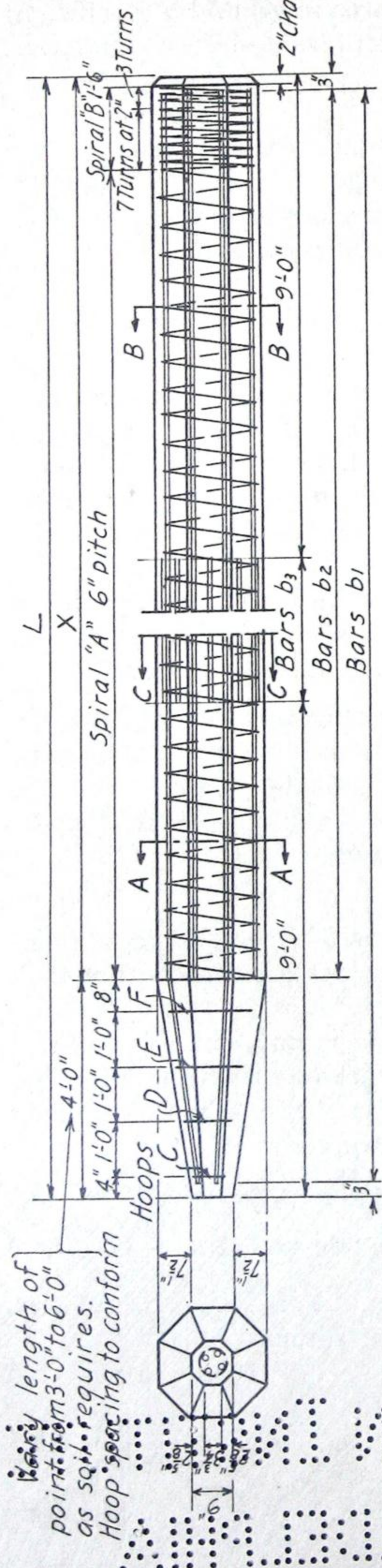
The procedure in cutting off 24-in. piles is to channel the pile at cut-off elevation down to the reinforcement, burn through the reinforcement with a torch, hitch a line around the pile end, then pull it off with the crane. Or a steel point may then be driven into the concrete at cut-off elevation; this acts as a wedge and is effective in snapping the head off. Air or electric cutting tools, supplied with power by a tie-tamper plant, do the channeling quickly and economically—comparing favorably with sawing off the ends of wooden piles.

The ease with which concrete piles can be spliced warrants continuation of driving beyond "cut-off" elevation if that is necessary to reach desired resistance to penetration. Two methods of splicing have been found satisfactory. One method is to remove the concrete to expose the reinforcement, clamp on forms, insert required lengths of reinforcement and fill the form with concrete. In the other method, holes to receive the splicing reinforcement are drilled into the pile top and the bars grouted in. The extension is then made with concrete cast in forms as in the first method. Where the splice is not betrayed by the color of the new concrete, close observation is necessary to discover it.

Shipping and Handling

Since economical design requires that no more reinforcement be used than necessary for handling, it is important that the stresses provided for be not greatly exceeded either in handling or shipping. Stresses resulting from insufficient support of piles while in transit may easily exceed those provided for in handling.

The resisting moment of 24-in. octagon piles based on working unit stresses in the steel, is shown on page 2. It is suggested that the computable stress, based on the spacing of blocking under piles on cars, should not exceed $\frac{2}{3}$ of this moment to provide additional safety against movement of the



* Column Strength P in lb.
* Resisting Moment when reinforced with P in lb.
* Length for P in lb.
* P Computed as a tied column.
* From $P = (1.33 - \frac{b}{L})$

REINFORCEMENT REQUIRED FOR HANDLING

Length	LONGITUDINALS				SPIRALS				HOOPS				Vol. of Pile C.Y.	Wt. of Pile Lb.
	Size	No.	Length	Wt.	Size	No.	Length	Wt.	Size	No.	Length	Wt.		
20'	1 1/2"	4	19'6"	147	1 1/2"	4	19'6"	147	1 1/2"	4	19'6"	147	2.22	9000
25'	2 1/2"	4	24'6"	189	2 1/2"	4	24'6"	189	2 1/2"	4	24'6"	189	2.83	11900
30'	3 1/2"	4	29'6"	232	3 1/2"	4	29'6"	232	3 1/2"	4	29'6"	232	3.45	14000
35'	4 1/2"	4	34'6"	275	4 1/2"	4	34'6"	275	4 1/2"	4	34'6"	275	4.06	16500
40'	5 1/2"	4	39'6"	318	5 1/2"	4	39'6"	318	5 1/2"	4	39'6"	318	4.68	18900
45'	6 1/2"	4	44'6"	361	6 1/2"	4	44'6"	361	6 1/2"	4	44'6"	361	5.29	21400
50'	7 1/2"	4	49'6"	404	7 1/2"	4	49'6"	404	7 1/2"	4	49'6"	404	5.91	24000
55'	8 1/2"	4	54'6"	447	8 1/2"	4	54'6"	447	8 1/2"	4	54'6"	447	6.52	26400
60'	9 1/2"	4	59'6"	490	9 1/2"	4	59'6"	490	9 1/2"	4	59'6"	490	7.14	28900

BILL OF BARS (FOR PILES WITH 4 FT POINT)

Length	LONGITUDINALS				SPIRALS				HOOPS				Vol. of Pile C.Y.	Wt. of Pile Lb.
	Size	No.	Length	Wt.	Size	No.	Length	Wt.	Size	No.	Length	Wt.		
20'	1 1/2"	4	19'6"	147	1 1/2"	4	19'6"	147	1 1/2"	4	19'6"	147	2.22	9000
25'	2 1/2"	4	24'6"	189	2 1/2"	4	24'6"	189	2 1/2"	4	24'6"	189	2.83	11900
30'	3 1/2"	4	29'6"	232	3 1/2"	4	29'6"	232	3 1/2"	4	29'6"	232	3.45	14000
35'	4 1/2"	4	34'6"	275	4 1/2"	4	34'6"	275	4 1/2"	4	34'6"	275	4.06	16500
40'	5 1/2"	4	39'6"	318	5 1/2"	4	39'6"	318	5 1/2"	4	39'6"	318	4.68	18900
45'	6 1/2"	4	44'6"	361	6 1/2"	4	44'6"	361	6 1/2"	4	44'6"	361	5.29	21400
50'	7 1/2"	4	49'6"	404	7 1/2"	4	49'6"	404	7 1/2"	4	49'6"	404	5.91	24000
55'	8 1/2"	4	54'6"	447	8 1/2"	4	54'6"	447	8 1/2"	4	54'6"	447	6.52	26400
60'	9 1/2"	4	59'6"	490	9 1/2"	4	59'6"	490	9 1/2"	4	59'6"	490	7.14	28900

Cross Section Perimeter 477sq.in.
Core diameter 21 in.
Core area 346 sq.in.
Concrete in 4ft. point 0.248 c.y.
Concrete in "X" per ft. 0.123 c.y.
Weight of point (4ft.) 1000 Lb.
Weight of "X" per ft. 498 Lb.

GENERAL NOTES
Specifications from A.R.E.A. Manual.
Class of concrete 3500
Permissible pile load $P = 75$ tons

24" REINFORCED CONCRETE OCTAGONAL PILE

blocks in transit, uneven level of blocks or distribution of load, and vibration and jarring in transit.

Shipping and handling stresses may exceed the working stresses used in design without material injury to the piles, so long as they are well within the elastic limit of the steel. Distributed and relatively small tension cracks in piles are not serious because, under load, piles are in compression and simple tension cracks are tightly closed.

The blocking under piles loaded on cars or stacked on the ground in tiers should be approximately in a vertical plane. Haphazard arrangement of the blocking may bring a large part of the entire weight of all piles above a certain tier on the piles or a pile of the lower tier.

The cost of very long piles may be materially reduced by providing for pick-up at several points so as to reduce handling moments to a minimum. Reinforcement is the largest single item of cost of concrete piles, and where a considerable number of long ones are used, the saving in reinforcement made possible by special handling devices may be much greater than the cost of these devices.

Cost

Quantities of concrete and steel are shown on page 2 for various lengths of 24-in. octagon piles. Appropriate unit prices applied to these quantities will give the cost per foot.

Manufacturing costs in a casting yard of a mid-western railway for the period December 1, 1933, to November 30, 1934, inclusive, were as follows:

Average Cost Per Foot of 24-in. Octagon Piles Ranging From 25 ft. to 60 ft. Long

Cement.....	\$0.29519
Ready Mixed Concrete.....	.30736†
Reinforcement.....	.43089
Labor.....	.17024
Miscellaneous*.....	.08233
Total.....	\$1.28601

The average cost per foot for various pile lengths was as follows:

Length	Cost per Foot
25 ft.....	\$1.0382
30 ft.....	1.1051
31 ft.....	1.1488
35 ft.....	1.1849
40 ft.....	1.3516
45 ft.....	1.3775
50 ft.....	1.5234
55 ft.....	1.5467
60 ft.....	1.5866

Practically all of the difference in cost of the piles is in the reinforcement which, of course, must be greater in the longer piles to provide for handling stresses.

The average cost of driving 24-in. piles, as determined by a midwestern railway system, is about 60 cents per ft., including digging holes, setting guide template and handling at the site.

Cost Per Ton Capacity

The cost per ton of capacity is the only correct basis for comparing the cost of different sized piles. On page 3 it is shown that for the soil resistance assumed a 24-in. octagon concrete pile has 2.8 times the load capacity of a round pile averaging 11 in. in diameter. The large pile must then cost in place 2.8 times as much as the smaller pile for *parity in first cost*.

From the above cost data we have for a 35-ft. 24-in. pile:

Manufacture.....	\$1.185 per ft.
Driving.....	.65 per ft.
Handling, Transportation, and Miscellaneous.....	.20 per ft.
	\$2.035 per ft.

Parity in first cost would then require that the smaller pile cost not to exceed 73 cents per foot in place.

Comparison of a 35-ft., 11-in. (av. diam.) pile on a ton capacity basis is more direct as follows:

Manufacture.....	\$0.50 per ft.
Driving.....	.35 per ft.
Handling, transportation and miscellaneous.....	.10 per ft.
	\$0.95 per ft.

Assuming 25 tons for this pile, the *cost per ton load capacity* = \$1.33.

The capacity of the 24-in. at 2.8 times the smaller would be 70 tons, and the *cost per ton* = \$1.02.

This result is substantiated by the fact that concrete piles were substituted for creosoted wooden piles to carry the new import-export pier of the Pennsylvania Railroad in Baltimore at *no extra cost to the railroad company*.

Specifications

Proposed revised specifications for manufacturing, handling and driving premolded reinforced concrete piles are published in A.R.E.A. Bulletin No. 374, pages 841 to 842. They are as follows:

PROPOSED REVISED SPECIFICATIONS FOR CONSTRUCTING PREMOLDED CONCRETE PILES

1. The workmanship, materials and proportioning shall conform to the Specifications for Concrete Plain and Reinforced of the American Railway Engineering Association, with the following modifications:

(a) *Aggregates*—The maximum size of the

coarse aggregate shall be not more than 1 in. nor more than $\frac{3}{4}$ of the minimum clear spacing of reinforcement or the minimum distance from reinforcement to forms.

2. Class of Concrete

The concrete shall be class 3500, using not more than 5 gallons of water per sack of cement.

*The item "Miscellaneous" amounts to about 6.8% of the total of the other items.
†Cement purchased by railroad.

3. Workability and Placement

The mixture shall be of workable consistency dependent on the method of placement to insure complete embedment of reinforcement and positive absence of honeycombing. Vibrating equipment shall preferably be used and it shall be of a type approved by the Engineer.

4. Curing

Moist curing shall be begun as soon as possible after completion of placement of the concrete and comply with "curing" specifications. The surface of the concrete shall be kept continually wet during the curing period. Curing shall be continued until the concrete has attained 2500 lb. per sq. in. as shown by test cylinders under like curing or as specified by the Engineer. Substitutes for moist

curing will be accepted only on specific permission of the Engineer.

6. Marking

Each pile shall be stamped or marked with the date of its manufacture. Lifting points indicated on plans shall be plainly marked.

7. Handling

Piles may be handled and driven only when the concrete has attained a compressive strength of 3500 lb. per sq. in. unless special provision is made for handling that will reduce the stresses in proportion to the strength of the concrete as shown by test cylinders cured under external conditions like those obtaining for the concrete in the piles. Piles shall be handled carefully, avoiding dropping or severe jarring while in a horizontal position.

PROPOSED SPECIFICATIONS FOR HANDLING AND DRIVING PREMOLDED CONCRETE PILES

Driving Cap

Piles shall be protected while being driven, with an approved cushion cap.

Driving Equipment

A steam hammer shall be used unless otherwise permitted by the Engineer. The weight of the hammer shall be adjusted to the weight of the piles driven. For driving piles larger than 18-in. diameter and 40-ft. long, a driver shall be used that strikes a blow equivalent in driving power to that produced by a weight of 7500 lb., falling freely through a distance of 3 ft. 6 in.

Jetting

Piles may be driven by the use of a water jet or water jets alone either with separate jet pipes or with pipes or holes within the pile, or in conjunction with a hammer. Equipment for an ample supply of water and adequate pressure shall be provided before jetting is begun.

Load Capacity

Where jetting is used, the bearing power shall be determined by test loads except that if a hammer is used in conjunction with jetting, and determination of load capacity from penetration under the hammer is specifically authorized by the Engineer, final driving may be deferred for a period ofhours.

Replacing and Re-driving

Any pile so injured in driving or handling as to

impair its structural integrity as a pile under the conditions of use shall be replaced by a new pile, the injured part replaced by splicing, or other remedial measures adopted—all as directed by the Engineer.

Unless otherwise called for on the plans, piles shall be driven as nearly as possible in a plumb position. Any pile so out of line or plumb as to impair its usefulness shall be pulled and re-driven or an additional pile driven, as required by the Engineer.

Sloping Ground

On sloping ground or under difficult conditions of driving, the pile shall be started in a hole or guiding templates or other means provided if necessary to insure driving in the proper location.

Cut-Off

Driving shall be continued until plan cut-off is reached or until the rate of penetration specified is obtained. If proper resistance to driving is not attained at cut-off, the driving shall be continued and the additional length of pile required shall be supplied by splicing in such a way as to develop the full strength of the section of the pile.

Delay in Driving

When driving is interrupted before final penetration is reached, record for penetration shall not be taken until after at least 12 in. penetration has been obtained on resumption of driving.